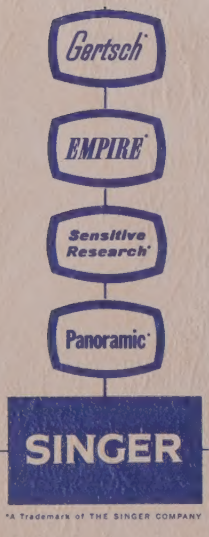
INSTRUCTION MANUAL

Gertsch*

RATIO TRANSFORMERS

MODELS RT-18 & RT-1695



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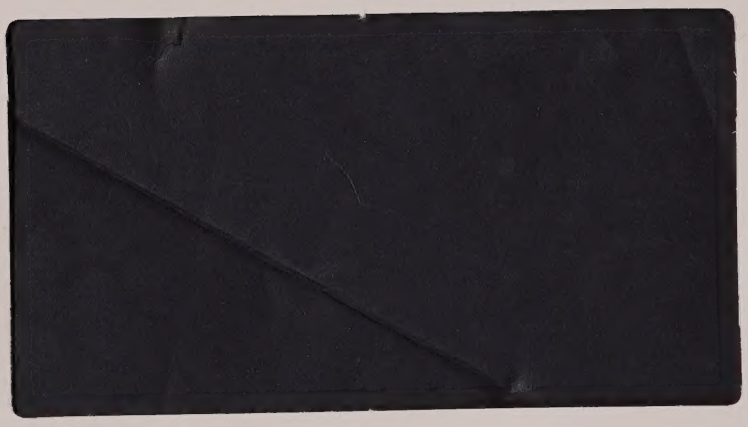

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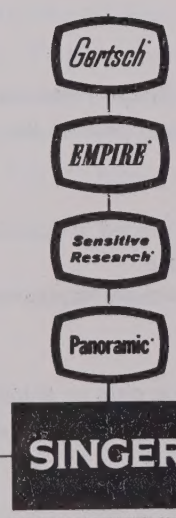

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8. Other comments

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Figure 1-1. Model RT-1695 Ratio Transformer

SECTION I
GENERAL DESCRIPTION

1-1. PURPOSE.

1-2. The ratio transformers are inductive voltage dividers providing an output voltage which is in a precise ratio to an input voltage. The ratio transformer can be used to measure the output voltage of a unit under test or to duplicate the voltage ratio output required of a unit under test.

1-3. DESCRIPTION.

1-4. The ratio transformer is a completely self-contained test unit which only requires connection to an input voltage for operation. The unit is designed for mounting in a standard 19 inch rack. A carrying case may be obtained as an optional extra.

1-5. The ratio accuracy, which is traceable to the US Bureau of Standards, is based on the use of a toroidal transformer and is not affected by age or environmental conditions. When driven by a constant voltage source, the internal impedance of the ratio transformer is low. The high input impedance allows use under a wide variety of test setups.

1-6. PREPARATION FOR USE.

1-7. No special precautions for unpacking are required other than that reasonable care must be taken when removing the unit from the shipping container. Installation consists only of mounting the unit in a rack.

TABLE 1-1. SPECIFICATIONS

ITEM	MODEL RT-18	MODEL RT-1695
Maximum Ratio	3.1111110	3.110
Resolution	0.00001% Steps	0.1% Steps
Accuracy of Indicated Ratio		
Ratios Less than Unity	$\pm (0.001 + \frac{0.0001}{\text{Ratio}})\%$ 50-@ 3000 cps	$\pm (0.005 + \frac{0.002}{\text{Ratio}})\%$ @ 60 cps
	$\pm (0.01 + \frac{0.001}{\text{Ratio}})\%$ 3000-@ 10,000 cps	$\pm (0.004 + \frac{0.0004}{\text{Ratio}})\%$ @ 400 cps
		$\pm (0.001 + \frac{0.0004}{\text{Ratio}})\%$ @ 1000 cps
Ratios Greater than Unity	$\pm \frac{0.5}{\text{f (f in cps)}}\%$ 50-@ 320 cps	$\pm$ 0.2% @ 60 cps
	$\pm$ (0.006 x Ratio - 0.003) $F^2\%$	$\pm$ 0.07% @ 400 - 1000 cps
	(F in KC) @ 320 - 10,000 cps	
Frequency Range	50 - 10,000 cps	30 - 1000 cps
Maximum Input Voltage	0.35f (f in cps), 350 V maximum	2.5f (f in cps), 170 V maximum
Maximum Effective Series Impedance		
R series		
Ratios less than 1	4 ohms + 75 uh	4 ohms + 75 uh
Ratios less than 2	15 ohms + 3 mh	18 ohms + 7mh
Ratios less than 3	35 ohms + 6 mh	48 ohms + 23mh
Size		
Rack	19" x 5-1/4" x 6" deep	19" x 3-1/2" x 17" deep
Case	21" x 5" x 6" high	

SECTION II
OPERATING INSTRUCTIONS

2-1. GENERAL.

2-2. A typical application of the ratio transformers is shown in figure 2-1. The output of the ratio transformers is compared to the output of the unit under test using a null indicator such as Gertsch Model NI-3 or a phase angle voltmeter such as Gertsch Model PAV-2. When the two outputs are exactly equal, the null indicator or phase angle voltmeter indicates a null. The input-to-output voltage ratio of the unit under test may then be read from the settings of the ratio transformers.

2-3. Additional applications are included in the Engineering Bulletins which are appended to this instruction book.

2-4. OPERATION.

2-5. To operate the ratio transformer, proceed as follows:

a. Connect input or reference voltage source to the I and C terminals.

(1) For the Model RT-18, make certain the input voltage is less than 0.35 times the frequency in cps of the input signal or 350 volts, whichever is less.

(2) For the Model RT-1695, make certain the input voltage is less than 2.5 times the frequency in cps of the input signal or 170 volts, whichever is less.

b. Make certain the input voltage does not contain a dc component. DC currents of more than a few microamperes will cause saturation of the input winding. If dc voltage is accidentally applied to the unit, degauss the unit as outlined in the maintenance section.

c. Make necessary connections to the O and C output terminals.

CAUTION

Do not apply voltage across the output terminals.

d. Turn the input voltage source ON.

e. Set the ratio transformer controls to the desired ratio or to the setting required to obtain a null.

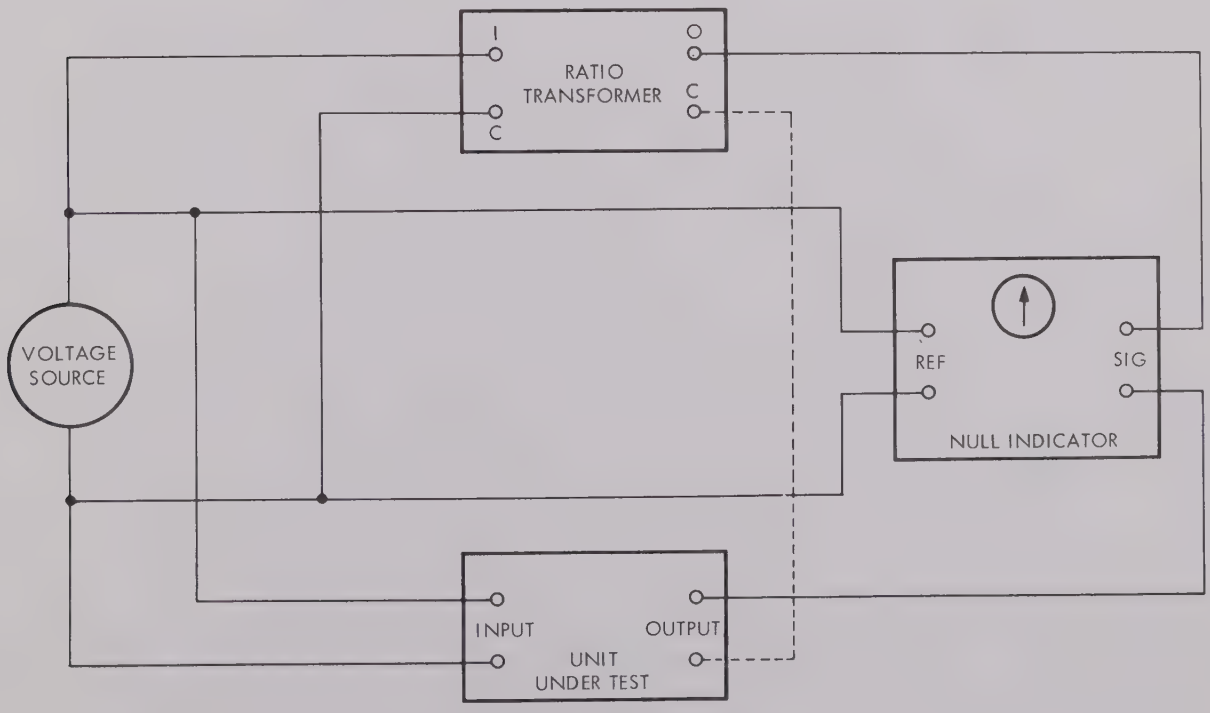

Figure 2-1. Typical Application

SECTION III
THEORY OF OPERATION

3-1. GENERAL. (See figure 3-1.)

3-2. The Model RT-1695 ratio transformer consists of a primary transformer, a 1:1 secondary and three tapped windings. For ratios of unity or less, a portion of the input voltage is selected from each tapped winding and these portions are added together to form the output voltage.

3-3. The full input voltage is applied across the primary and thus across the first tapped winding. The first winding is tapped to provide ten precise voltage outputs. The lower wiper arm of switch SW-2 can select any one of ten voltages between 0.1 and 1.0. The two wiper arms of switch SW-2 supply reference points to the succeeding decade winding. The lower wiper arm of switch SW-3 selects a 0.01 to 0.10 (X) portion of the input voltage which is added to the voltage selected by switch SW-2. The final and smallest portion is selected by switch SW-4.

3-4. For greater than unity ratios, the tapped windings are placed in series with the primary or the primary and untapped secondary by switch SW-1. The unit then operates as a step-up autotransformer.

3-5. Both the input and output circuits are fused. Switching transients are virtually eliminated by the resistors which maintain continuity between steps while settings are being changed.

3-6. The Model RT-18 operates in the same manner. Four additional decade windings are added to increase resolution.

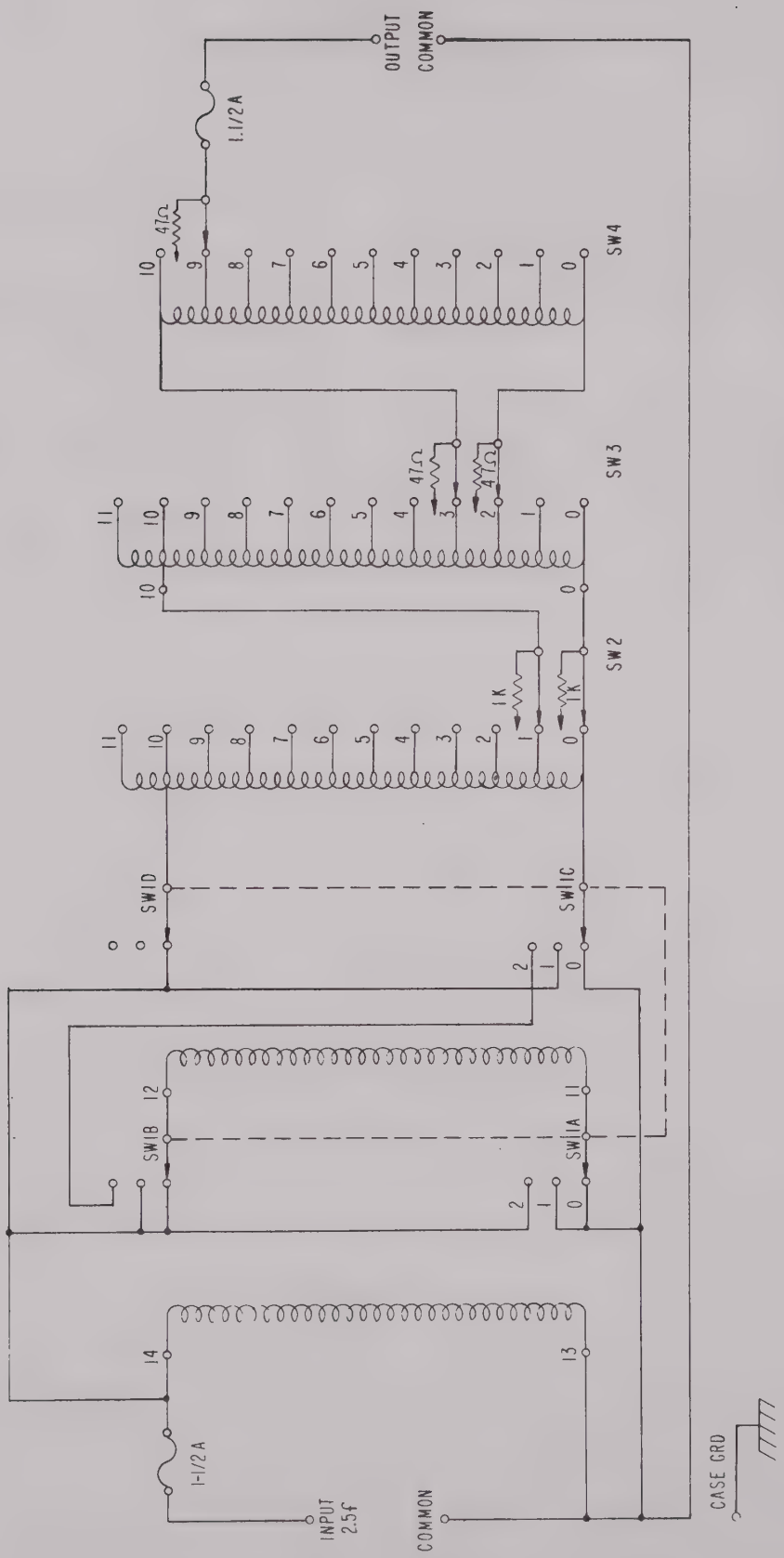

Figure 3-1. Equivalent Schematic, Model RT-1695

SECTION IV
MAINTENANCE

4-1. GENERAL.

4-2. Since the ratio transformers are passive devices, a minimum of maintenance is required. With the exception of cleaning switch contacts, no maintenance on a regularly scheduled basis is required. Moving parts are lubricated at the factory and should require no further lubrication.

4-3. SWITCH CONTACTS.

4-4. Once every three to six months, clean switch contacts with a good grade of solvent such as alcohol or acetone. Relubricate contacts with a layer of vaseline.

4-5. DEGAUSSING, MODEL RT-18.

4-6. To degauss the 0.35f units, proceed as follows:

a. Connect a 1K resistor in series with the input connection.

b. By means of a variac or other suitable voltage control, apply a 60 cps signal between the open end of the 1K resistor and the common terminal.

c. Starting with the voltage control at zero, increase voltage to 40 vrms.

d. Slowly decrease the voltage to zero. The period of time to reduce the voltage from 40 vrms to zero should be between 10 and 15 seconds.

4-7. DEGAUSSING, MODEL RT-1695.

4-8. To degauss the 2.5f unit, proceed as follows:

a. Set the ratio transformer section to a 0.100000 ratio.

b. Connect a 1K resistor in series with the 0 output terminal.

c. By means of a variac or other suitable voltage control, apply a 60 cps signal between the open end of the 1K resistor and the common terminal.

d. Starting with the voltage control at zero, increase voltage to 30 vrms.

e. Slowly decrease the voltage to zero. The period of time required to reduce the voltage from 30 vrms to zero should be between 10 and 15 seconds.

SECTION V
CALIBRATION

5-1. GENERAL.

5-2. The accuracy of the unit should be maintained for a period of not less than three years, provided that the unit is kept in a normal laboratory environment, has clean low resistance contacts, and does not suffer injury or insulation damage.

5-3. Under the above conditions, the unit should only require a calibration check every three years. Under more severe conditions, the calibration period must be shortened.

5-4. This section includes two tests: an input impedance test and a simplified ratio accuracy test. Refer to Table 5-1 for a list of test equipment required. For a complete calibration procedure, refer to National Bureau of Standards Report 6738.

5-5. IMPEDANCE CHECK, MODEL RT-18.

5-6. To check input impedance, proceed as follows:

a. Connect unit into test setup as shown in figure 5-1.

b. Set input frequency to 400 cps.

c. Adjust voltage source until VTVM VI indicates twice the desired voltage through the unit under test.

d. Adjust decade resistance box until VTVM V2 shows equal indications with switch SW-1 in either position A or B.

e. Read input impedance from the decade resistance box. The input impedance shall be 200K or more.

5-7. IMPEDANCE CHECK, MODEL RT-1695.

5-8. To check input impedance, proceed as follows:

a. Connect unit into test setup as shown in figure 5-1.

b. Set input frequency to 60 cps.

c. Adjust voltage source until VTVM VI indicates twice the desired voltage through the unit under test.

d. Adjust decade resistance box until VTVM V2 shows equal indications with switch SW-1 in either position A or B.

e. Read input impedance from the decade resistance box. The input impedance shall be 10K or more.

5-9. RATIO ACCURACY TEST. (Ratios less than unity.)

5-10. To test the ratio accuracy proceed as follows:

a. Connect unit into test setup as shown in figure 5-2.

b. For the Model RT-18, set input frequency to 400 cps. For the Model RT-1695, set input frequency to 60 cps.

c. Apply input voltage of 25 vac as indicated in VTVM VI.

d. Set RT standard controls for an output reading of 0.0000000.

e. Adjust unit under test controls until the null indicator indicates a null.

f. Check the ratio indicated by the unit under test against the ratio indicated by the RT standard unit. The two ratios shall agree within the "Accuracy of Indicated Ratio" figure listed in the Table of Specifications.

g. Repeat steps e through f for each switch position of the RT standard unit (0.11111, 0.22222, etc.).

5-11. RATIO ACCURACY TEST. (Ratios Greater than Unity.)

5-12. To test greater-than-unity ratio accuracy, proceed as follows:

a. Connect unit into test setup as shown in figure 5-3.

b. Apply input voltage of 25 vac as indicated on VTVM VI.

c. Set No. 1 and No. 2 RT Standard controls to a ratio of 0.500000.

d. Set unit-under-test controls to a ratio of 1.X00.

e. Set switch SW-1 to the No. 2 position.

f. Adjust No. 1 RT standard as required to obtain a null.

g. Set switch SW-1 to the No. 1 position.

h. Adjust No. 2 RT standard as required to obtain a null (approximately unity -1.000000).

i. The deviation of the No. 2 RT standard from unity indicates error directly in percentage. This error shall be within the limits set by the "Accuracy of Indicated Ratio" figure listed in the Table of Specifications. See Table 5-2 for typical accuracy figures.

j. Repeat steps c through i with the unit-under-test set to 2.000.

k. Repeat steps c through i with the RT standards set to 0.3333$\overline{3}$33 and the unit-under-test set to 3.000.

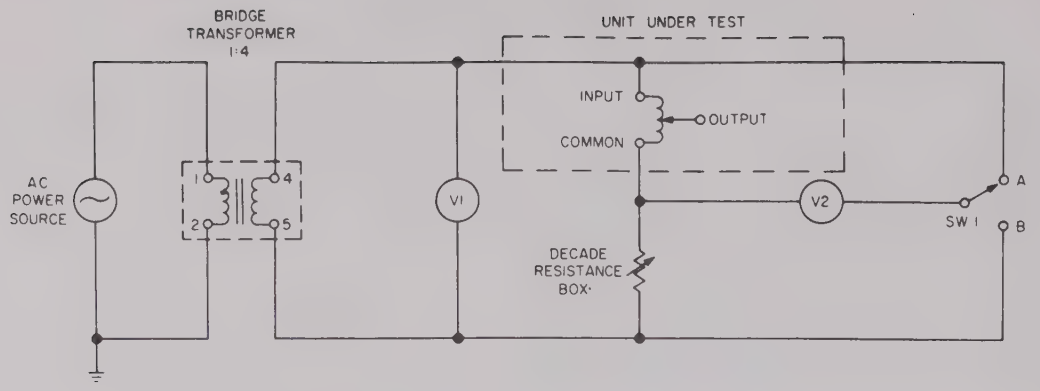

Figure 5-1. Impedance Test Setup

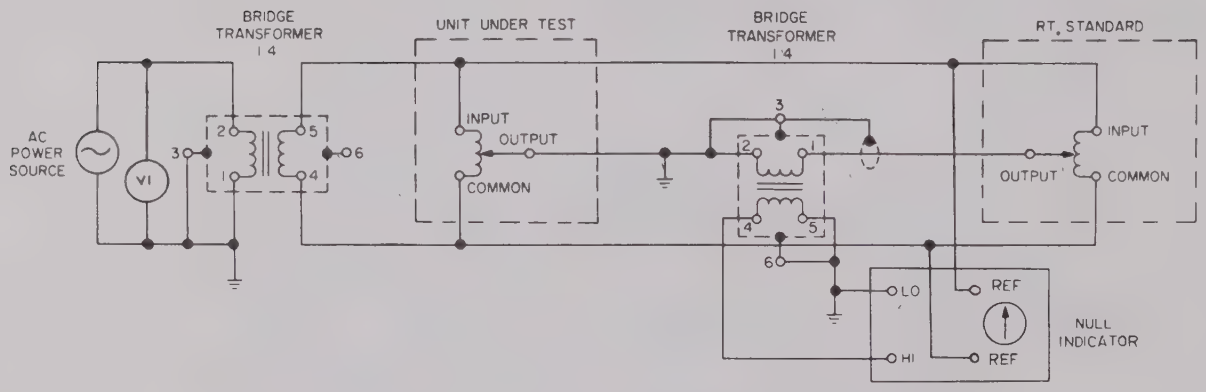

Figure 5-2. Ratio Accuracy Test

TABLE 5-1. LIST OF TEST EQUIPMENT

NOMENCLATURE	PART NUMBER OR MODEL	APPLICATION	RANGE	ACCURACY
AC Ratio Standard	Model 1011 (Singer Metrics)	Provides comparison standard for ratio test	1.111111 to -0.1111111 ratios	Per National Bureau of Standards Calibration Test
Bridge Transformer	Model ST100 (Singer Metrics)	Provides voltage take-off	120 vac, 400 cps (maximum)	
Null Indicator	Model NI-3 (Singer Metrics)	Provides means of comparing output voltage		
Decade Resistance Box		Provides voltage divider network	1 megohm range	±0.5%
Vacuum Tube Voltmeter	Model 410B (Hewlett-Packard)	Measuring voltages		±0.5%
Switch		Check voltage divider network	SPDT	

TABLE 5-2. TYPICAL ACCURACY LIMITS (Ratios Greater Than Unity)

FREQUENCY		NO. 2 RT STANDARD LIMITS		
		RT-18 TEST		RT-1695 TEST
		X2 Ratio	X1 Ratio	
60 cps	Maximum	1.0083300	1.0083300	1.0020000
	Minimum	.9916700	.9916700	.9980000
400 cps	Maximum	1.0000144	1.0000240	1.0007000
	Minimum	.9999856	.9999760	.9993000
1000 cps	Maximum	1.0000900	1.0001500	1.0007000
	Minimum	.9999100	9998500	.9993000

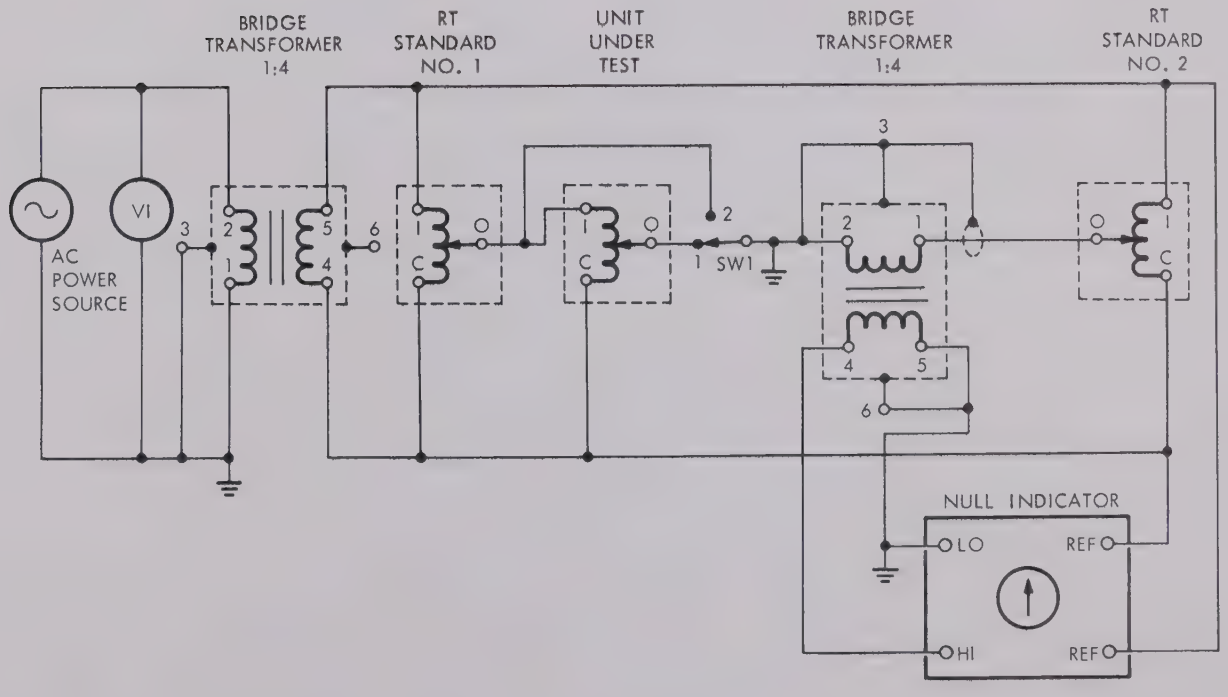

Figure 5-3. Ratio Accuracy Test Setup (Greater Than Unity Ratios)

SECTION VI
PARTS LIST

MODELS RT-18 & RT-18R

ITEM	PART NO.	MFR	QTY	
			RT-18	RT-18R
Binding Post, Red	DF30RC	Superior	2	4
Binding Post, Black	DF30BC	Superior	2	4
Binding Post	938A	Gen. Radio	1	2
Fuse, 1-1/2 amp	MDL 1-1/2	Bussmann	2	2
Fuseholder	342004	Littelfuse	2	2
Window, Dial Readout	MM23-1	Singer	8	8
Knob	OP-1	Singer	8	8
Dial Assembly, Face side hub	AA-240-1	Singer	4	4
Dial Assembly, Back side hub	AA-240-2	Singer	4	4
Switch, 0, 1, 2	SW-56	Singer	1	1
Switch Assy, 10^{-1}	AA-333-1	Singer	1	1
Switch	SW-53	Singer	1	1
Resistor, comp, 1K ±10%, 1/2W			1	1
Switch Assy, 10^{-2} 10^{-7}	AA-333-2	Singer	6	6
Switch	SW-53	Singer	6	6
Resistor, 47 ohms ±10%, 1/2W			6	6
Transformer Assy, Input	TA-119	Singer	1	1
Transformer Assy, Output	TA-135	Singer	1	1

SECTION VII
PARTS LIST

MODEL RT-1695

ITEM	PART NO.	MFR	QTY
Binding Post, Red	29-3 Red	Grayhill	4
Binding Post, Black	29-3 Blk	Grayhill	4
Binding Post, White	29-3 Wht	Grayhill	4
Fuse, 1-1/2 amp	MDL 1-1/2	Bussmann	4
Fuseholder	342004	Littelfuse	4
Knob	OP-1	Singer	4
Dial. switch	AW-694	Singer	4
Switch, SW-1	SW-279	Singer	1
Switch, SW-2, SW-3	SW-280	Singer	2
Switch, SW-4	SW-281	Singer	1
Resistor, 1K ±10%, 1/2W			2
Resistor, 47 ohms ±10%, 1/2W			3
Transformer	TA-459	Singer	1

RatioTran*

ENGINEERING BULLETINS

The following Engineering Bulletins cover the theory and applications of Gertsch RatioTrans.

BULLETIN NO. 1	Theoretical Analysis of Accuracy of Ratio Transformers
BULLETIN NO. 2	Use of Gertsch Standard Ratio Transformers for Low Impedance Voltmeter Calibration
BULLETIN NO. 3	Accuracy Calculations for Gertsch Standard Ratio Transformers
BULLETIN NO. 4	Use of RatioTran in Bridge Circuits
BULLETIN NO. 5	Measuring Small Phase Angles
BULLETIN NO. 6	The Rotary RatioTran
BULLETIN NO. 7	Use of a Gertsch Rotary RatioTran for Calibration of Precision Potentiometers

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THEORETICAL ANALYSIS OF ACCURACY OF RATIO TRANSFORMERS (RatioTran)*

Theoretical analysis of a perfect autotransformer used for stepdown purposes shows that if leakage inductance and winding resistance are uniformly distributed and the turns can be accurately tapped, the accuracy as a voltage divider for no load is perfect.

Consider first the effects of leakage inductance. The most symmetric configuration insofar as flux is concerned is the uniformly wound toroid. By suitably interleaving the windings and carefully maintaining uniformity, the total leakage inductance can be kept to under 10% of the air core inductance. Since the air core inductance is approximately 1/u times the inductance with iron core, where u is the permeability of the core material, the total leakage inductance to coupled inductance ratio is 1/10u. The core material used in the transformers is supermalloy which has a guaranteed initial permeability of 55,000. The leakage to coupled inductance ratio is therefore approximately .0002%. Since this figure represents the ratio of voltage dropped in the leakage inductance to total voltage, the error in the transformer due to non-distributed leakage inductance will not exceed this, if the leakage inductance per turn does not vary by more than ±100%. This condition can be met with suitable techniques of interleaving the windings.

Non-distributed winding resistance has much the same effect as non-distributed leakage inductance. If the effects of winding capacitance are neglected, the winding resistance is most important at low frequencies since the exciting impedance of the transformer is directly proportional to frequency. Since the exciting impedance is fairly reactive, the voltage dropped in the winding resistance will be almost in quadrature with the input and consequently any non-distributed resistance will cause some phase error as well as magnitude error. The fact that this error voltage is in quadrature makes the magnitude error extremely small and for all practical purposes negligible. Typical figures might be .000001% for small ratios and even less for larger ratios. Phase angles from this cause would be approximately .01 milliradians at low frequencies and small ratios decreasing for larger ratios.

At higher frequencies distributed capacitance becomes important. It causes voltage drops in the leakage inductance and winding resistance which are not uniformly distributed due to the transformer action. Like the effects of winding resistance, the errors caused by the capacitance are mainly in quadrature and so cause phase shift at low ratios. Typical values for this phase shift are:

Less than .05 milliradians for frequencies below 1 KC and ratios above .1 for low voltage - high frequency units.

Less than .05 milliradians for frequencies below 200 cps and ratios above .1 for high voltage low frequency units.

Phase angle due to this cause is almost directly proportional to frequency for any particular ratio down to frequencies where the non-distributed resistance takes over.

Other sources of error are:

1. Voltage drops due to exciting current in the leads to the transformer.
2. Loading effects of the potentiometers.
3. Non-linearity and end effects of the potentiometer.

The first of these effects may be minimized by using heavy connecting leads or treating the transformer as a four terminal impedance. The internal wiring of the transformers contributes to this error. These effects are worse at higher frequencies, above the self-resonant frequencies of the transformers.

The potentiometers cause some loading effects on the transformers due to the internal impedances of the windings and switch contacts.

For units with the 10 turn potentiometer, such as the RT-1 and Model RT-10, the errors due to this cause are approximately .0001% of the input. In the single turn units this error amounts to about .00001%. The single turn potentiometer causes less error than the 10 turn since the voltage across it is .001% of the input in comparison to .1% across the 10 turn potentiometer.

Non-linearity and end effects of the potentiometer may cause an error of approximately .0005% of the input in the case of the units with the 10 turn potentiometers. The single turn potentiometers may cause an error of .00001% of the input.

From the foregoing considerations a reasonable terminal linearity figure of .001% is derived. The usual definition of terminal linearity is the error in the output divided by the total input:

$$\text{Terminal Linearity} = \frac{\triangle E_o}{E_{IN}}$$

where $\triangle E_o$ is the actual error voltage in the output and E_{IN} is the total input voltage.

An accuracy figure in terms of the output voltage would be

$$\text{Ratio Accuracy} = \frac{\triangle E_o}{E_o}$$

where $\triangle E_o$ is the actual error voltage in the output and E_o is the total output voltage.

When the ratio gets small, the error caused by pot loading, pot non-linearity, and lead drops become predominant. Since these errors are constant in absolute value, their fractional value in terms of the output is inversly proportional to the ratio of the transformer. Taking this into account a reasonable ratio accuracy for the three decade units with the 10 turn pot is:

$$\text{Ratio Accuracy} \pm \left(.001\% + \frac{.0006\%}{R}\right)$$

(This applies to Models RT-1 & 10 and for the 5 decade units, with or without the single turn pot:

$$\text{Ratio Accuracy} \pm \left(.001\% + \frac{.0001\%}{R}\right)$$

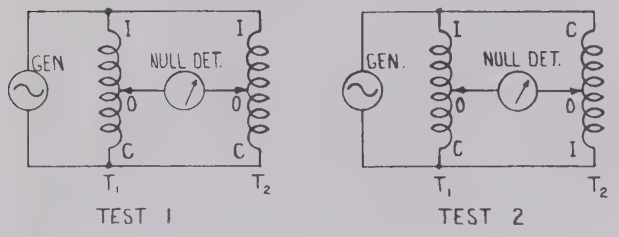
where R is the indicated ratio of the transformer. (This applies to all Models except RT-1 & 10)

Standards suitable for certifying transformers to the accuracy figures quoted are not generally available. It can be seen, however, from the foregoing discussions that the transformers are inherently excellent voltage dividers. They can be considered primary standards of ratio in that one can be constructed by following assembly instructions and requiring no measurements or calibrations other than wiring checks and tests to make certain that the number of turns is correct. A unit so constructed will match any other unit so constructed to well within the specifications

* *Trademark*

quoted above. The units are ageless, requiring no calibration tests and should perform indefinitely with no loss in accuracy barring some switch failure or actual damage to the transformer.

Tests have been performed on a basis of comparison between several units. While it is not possible to get complete absolute data in this manner, certain facts can be deduced. Referring to the diagram T_1 and T_2 represent the two transformers under test.



Let R_1 be indicated ratio of T_1
R_2 be indicated ratio of T_2

Let E_1 be error in indicated Ratio of T_1
E_2 be error in indicated Ratio of T_2

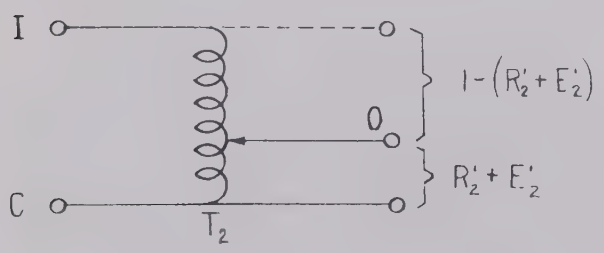
then at balance in Test 1

$R_1 + E_1 = R_2 + E_2$

at Balance in Test 2

$R_1 + E_1 = 1 - (R_2' + E_2')$

where $1 - (R_2' + E_2')$ is the complement of $R_2' + E_2'$ as shown below



Now suppose that in both tests

$R_1 = R_2$
$R_1 = 1 - R_2'$

then $E_1 = E_2$

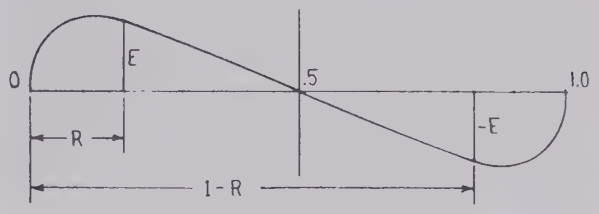
$E_2' = -E_1$

or $E_2' = -E_2$

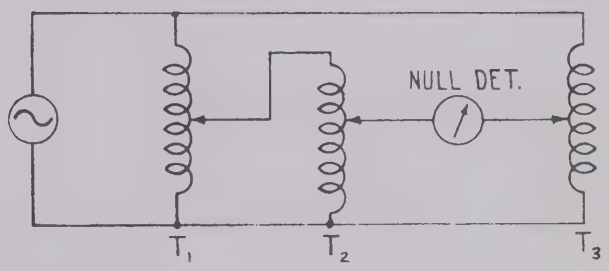
This shows that if at balance in both tests the indicated are exactly equal or complementary there can exist an error of a special nature which cannot be detected.

E at R = -E at (1-R)

E must be zero at R = .5 and show odd symmetry about R = .5



In general, any two transformers so tested will meet the conditions for the tests within 1 or 2 parts in 10^6 so that any components of error which do not show the above symmetry must be at least this small. To obtain some idea of the absolute errors two transformers were cascaded and compared against a third as shown below.



$(R_1 + E_1)(R_2 + E_2) = (R_3 + E_3)$ at Balance

if we choose $R_1 = R_2 = .5$

from the foregoing analysis $E_1 \quad E_2 \quad 0$

If proper care is taken to compensate for loading effects the magnitude of E_3 can be determined at $R_3 \quad .25$. This error in general is less than .001%.

This process can be continued by cascading more transformers and measuring the error at points $R = (.5)^N$

It is easy to show that the same analysis applies to quadrature voltage. The same tests can be made and values of 0 at points $R = (.5)^N$ determined. The phase angle data given earlier in this article was derived in this manner.

All of the foregoing discussions apply to completely unloaded conditions on the transformers. Effects of loading are discussed in Engineering Bulletin No. 3 entitled "Accuracy Calculations for Gertsch Standard Ratio Transformers."

Accuracy formulas given above apply only to those units shipped after January 1, 1956. Previous units have accuracies of $\pm(.004\% + \frac{.0006\%}{R})$ and

$\pm(.004\% + \frac{.0001\%}{R})$ respectively.

USE OF GERTSCH STANDARD RATIO TRANSFORMERS (RatioTran*) FOR LOW IMPEDANCE VOLTMETER CALIBRATION

The RT Series Standard Ratio Transformers are very useful for AC voltmeter calibrations. Basically, the system consists of a standard voltage source driving the RatioTran* which in turn drives the meter to be calibrated.

Several things must be taken into consideration in this system. The source voltage must be known at least as accurately as the calibration to be made. The distortion of the source must be low, particularly in a case where the meter which is monitoring the source measures on a different basis from the meter to be calibrated. For example, the monitoring meter might read RMS voltage and the meter to be calibrated might read average voltage.

The loading effects of the meter to be calibrated on the RatioTran* should be taken into consideration. These loading effects can be easily determined from the ratio of meter impedance to ratio transformer impedance. For all practical purposes the ratio transformer impedance is resistive and forms, with the meter to be calibrated, a voltage divider. Therefore, if the voltmeter is resistive, the voltage appearing across it will be low by an amount equal to the ratio between the RatioTran* resistance and the meter resistance. For example, if the RatioTran* has an internal impedance of 5 ohms and the meter has a resistance of 5,000 ohms, the voltage appearing across the meter will be 5/5000 or .1% lower than it would be if the meter had infinite impedance.

The foregoing analysis can be generalized. The fractional error that will exist with the RatioTran* resistance R and meter resistance M is approximately equal to $\frac{R}{M}$, or stating it a different way, for a maximum error E the meter resistance M must be greater than $\frac{R}{E}$, where R is again the series impedance of the RatioTran.*

The maximum series impedance in any of the ratio transformers for nominal frequencies is less than 5 ohms with the exception of the RT-1 and RT-10 where the maximum is 12 ohms. Consequently, for meter impedance of 5,000 ohms or greater the error introduced by loading effects on the ratio transformers will not be greater than .1% for all ratio transformers except the RT-1 and RT-10, in which case for the same accuracy the meter resistance must not be less than 12,000 ohms.

If greater accuracies are desired or the meter impedance is lower than the values given above, power must be supplied to the meter in a bridge arrangement shown in Figure 1. With this circuit it is possible to adjust the variable series impedance so that all the power supplied to the meter comes from this branch. This, of course, occurs when the bridge is balanced, that is, the ratio of the meter impedance to the total impedance (meter impedance plus variable impedance) is equal to the ratio of the Standard Ratio Transformer. Obviously, when the bridge is balanced there is no current flow through the ratio arm of the transformer and the junction between the series impedance and the meter so there is effectively no load on the ratio transformer.

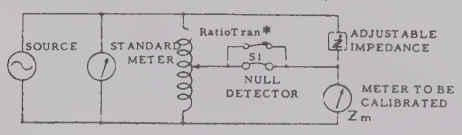


FIG. 1

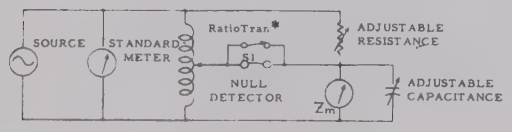


FIG. 1A
Modification of Fig. 1
CONVENIENT WHEN Z_m CONTAINS INDUCTIVE REACTANCE

Since we can make the ratio transformer operate essentially unloaded by this method, meters with impedance as low as desired can be calibrated with no loss in accuracy.

One other restriction must be placed on the variable impedance in series with the meter. It must have the same phase angle as the meter. The total requirement can be stated generally as follows: the ratio of the complex impedances of a meter and series impedance must be real and equal to $\frac{N}{1-N}$ where N is the ratio on the ratio transformer. Here we have assumed that the Ratio Transformer has zero phase shift.

This last statement is merely another way of saying that the bridge formed must be balanced.

The degree of unbalance which can be tolerated in the bridge circuit can best be expressed in terms of the unbalanced current flowing in the ratio arm of the transformer. Since the product of the unbalanced current times the effective impedance in the ratio arm gives the magnitude of the error voltage, the maximum value of this current can be easily determined. It would be simply E Max. divided by R Max. where E is the maximum allowable error voltage and R is the maximum series impedance in the ratio arm of the transformer.

The unbalanced current itself may be measured directly with a high sensitivity AC current meter, or the bridge may be brought to balance with standard null detector techniques. The null detector should be shorted out with switch, S1, after balance has been reached. This last step is recommended since the voltage at the junction between the series impedance and the meter will always be closer to the true voltage for small errors if the null detector is shorted out.

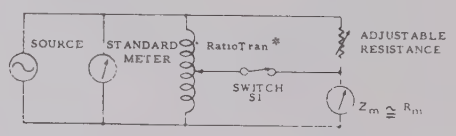


FIG. 2

SUITABLE ONLY WHEN Z_m IS RESISTIVE OR NEARLY RESISTIVE

If the phase angle of the meter is known to be small this series impedance may be resistive and balance of the bridge can be detected with a circuit shown in Figure 2. The switch, S_1, is alternately opened and closed and the series impedance adjusted so that the meter reads the same whether the switch is opened or closed. When this occurs the bridge is balanced provided the phase angle of the meter is small. The phase angle requirement must be met because it is possible, in this test, for the meter to read the same whether the switch is opened or closed and still not have the voltage across it equal to the open circuit voltage of the ratio transformer, when the phase angle of the meter in the series impedance are not equal. The allowable phase angle can be determined from the circuit constants and the accuracy desired, or a direct measurement of the unbalanced current may be made.

For maximum accuracy of calibration the RatioTran* should not be used to divide the standard source too far. The reason for this is, the accuracy of the ratio decreases for small ratios between output and input of the RatioTran.* To guarantee accuracies better than .02% it would be necessary to operate with ratios larger than .01. To extend the system range below .01 a new standard voltage one 100th the original standard voltage could be derived with the RatioTran* and this used to extend the system on down by another factor of 100. In this manner a total range of 10,000 to 1 can be covered with less than .04% error. One method of doing this is to connect two ratio transformers in cascade. The percentage errors of the two transformers can be added in this case.

* *Trademark*

Engineering Bulletin Number 3

ACCURACY CALCULATIONS FOR GERTSCH STANDARD RATIO TRANSFORMERS (RatioTran*)

1. DEFINITION

The accuracy of Gertsch Standard Ratio Transformers is specified by a formula which gives the maximum error which could be expected in the indicated ratio. This would give the error as a percentage of the output if the input is perfectly known. This accuracy is applicable to a bridge circuit, since the source voltage is common to both branches of the bridge circuit and variations of source voltage cause no error. The accuracy specification is given as a formula similar to $\pm\ (.004\% + \frac{.0001\%)}{R}$ where R is the indicated ratio in the decimal fraction form with which the RatioTran* switches are calibrated. This formula gives a more accurate description of the maximum error which could be expected from a Gertsch RatioTran* than would be obtained by the standard definition of terminal linearity. In a potentiometer terminal linearity rating, the error component which is to be expected at the output is quoted as a percentage of the input voltage. A comparison of the specified maximum error in a RatioTran* and a potentiometer of .005% terminal linearity is given in the following table.

ERROR EXPRESSED AS PERCENTAGE OF OUTPUT			
Ratio	Ratio Transformer Units Shipped Prior to 1/1/56 $\pm(.004\% + \frac{.0001\%)}{R}$	Ratio Transformer Units Shipped After 1/1/56 $\pm(.001\% + \frac{.0001\%)}{R}$	Potentiometer .005% Terminal Linearity
1.0	± .0041%*	± .0011%*	± .005%
.1	± .005%	± .002%	± .05%
.01	± .014%	± .011%*	± .5%
.001	± .104%*	± .101%*	± 5%

*This is the exact solution of the formula. Since "error" is only roughly specified, all digits beyond the first significant figure are meaningless.

2. ACCURACY vs AGE

A careful study of the distribution of resistance and reactance in RatioTrans* leads us to believe that it is extremely improbable that the specified values of error will ever be exceeded. The accuracy of Gertsch RatioTrans* does not change appreciably with age and periodic calibration checks are unnecessary. Any periodic checks should be directed chiefly at detecting malfunctioning switches or potentiometers.

3. ACCURACY UNDER LOAD

Gertsch Standard Ratio Transformers have an internal impedance which can be considered to be in series with the output (see Fig. 1).

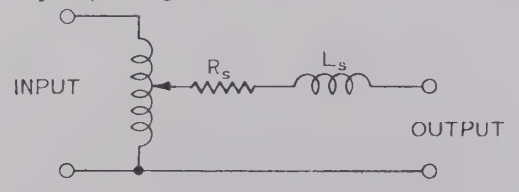


FIG. 1

The value of this impedance varies with ratio in a manner which makes it impractical to define it as a function of ratio. Instead, maximum values of resistance and reactance that can be expected at the worst possible setting of the instrument are given. Voltage drop in the RatioTran* will always be less than the value found by multiplying the load current by the specified maximum series impedance. If the impedance of the load is known, the error introduced by this impedance will always be less than the ratio of the specified maximum impedance to the load. As a numerical example, suppose that a 10,000 ohm resistive load is to be driven from a Model RT-5 operating at 400 cycles. The RT-5 has a maximum effective series inductance of 75 uh. At 400 cycles this is an inductive reactance of .2 ohms, and, for the purposes of this problem, it may be neglected since it is much less than the 3 ohms maximum effective series resistance. The RT-5 may be assumed to have a series impedance of 3 ohms or less resistive. When loaded by 10,000 ohms, the fraction of output voltage dropped across the internal impedance of the RT-5 is given by:

$$\frac{Edrop}{Eout} = \frac{Rseries}{Rload + Rseries} = \frac{3}{10{,}000 + 3} \simeq \frac{3}{10{,}000} = .0003 = .03\%$$

In this case the percentage error contributed from this source is .03%. If this error is acceptable, the circuit may be used. Otherwise a bridge circuit must be devised which will drive the required load impedance without loading the Ratio Transformer beyond the acceptable current level. Circuits for this purpose are discussed in another paper distributed by Gertsch Products, Inc. The title of this paper is Engineering Bulletin No. 2 (RatioTran*) "Use of Gertsch Standard Ratio Transformers For Low Impedance Voltmeter Calibration."

* *Trademark*

Engineering Bulletin Number 4

USE OF RatioTran* IN BRIDGE CIRCUITS

Since any bridge circuit has four terminals, only one of which may be grounded, it is recommended that a shielded bridge transformer such as the Gertsch Model ST100 or ST100A be used to isolate either the generator or detector. Typical circuits are shown below.

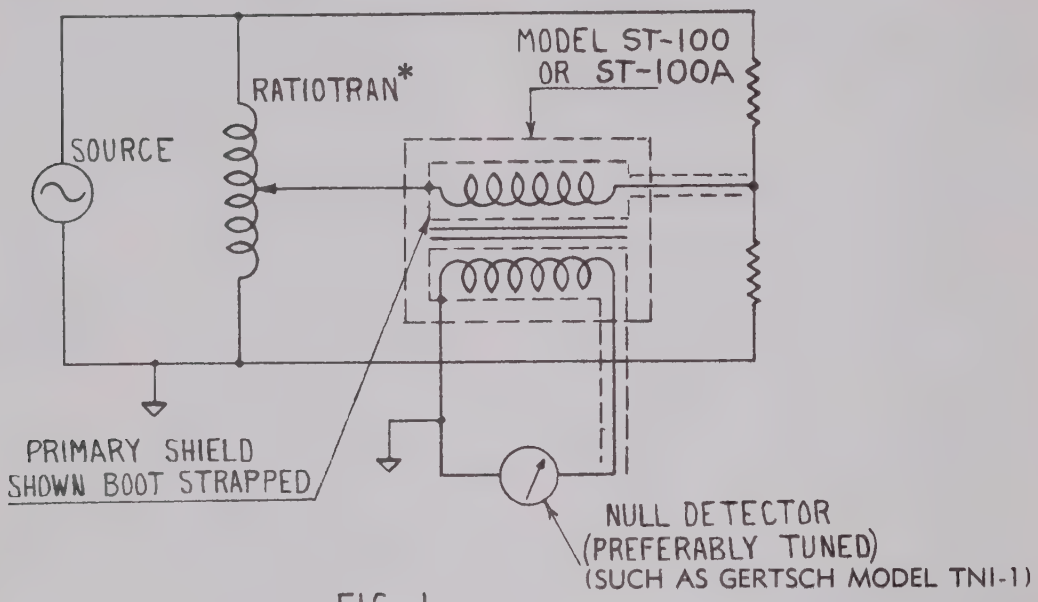


FIG. 1

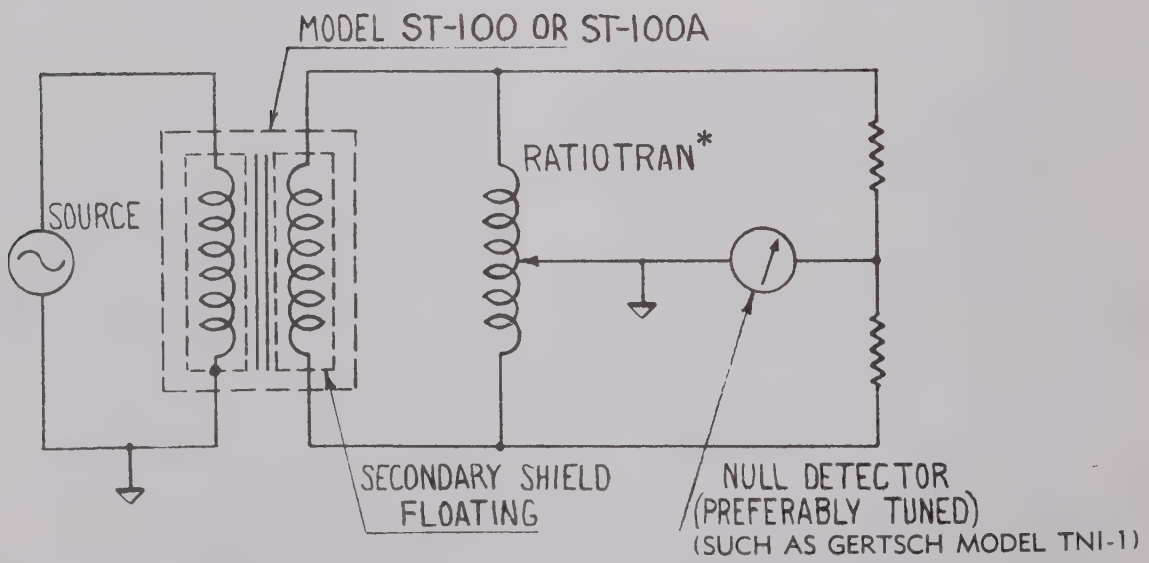


FIG. 2

The degree of shielding of the various bridge elements used depends on impedances and accuracy desired. For a good treatment on AC Bridge technique the reader is referred to "Electronic Measurements" - Terman & Pettit.

* *Trademark*

Gertsch PRODUCTS, INC.

Engineering Bulletin Number 5

The following article originally appeared in the January 1956 issue of Control Engineering and is reprinted here with the permission of Control Engineering and the author, Mr. Jack Gilbert.

Measuring Small Phase Angles

JACK GILBERT, Norden Laboratories

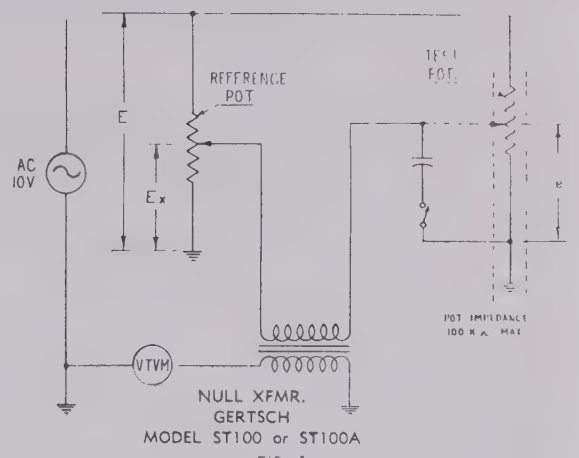


FIG 1

Phase shift due to potentiometers, precision resistors, computer amplifiers, ac tachometers, and transformer windings can be found by a relatively simple technique that can measure phase angles as small as 0.005 deg and as large as 30 deg. With some loss of accuracy, angles up to 90 deg can also be detected by the method. The detection circuit, with elements of only conventional accuracy, obtains phase shift and quadrature voltage from a reference voltage varying from 50 to 5,000 cps. And the result is accurate to plus or minus 0.01 deg plus or minus 5 per cent at midband (350—1000 cps).

The reference voltage, E, is divided by the reference pot slider until a minimum or null reading is observed on the vacuum tube voltmeter. This voltmeter reading will be the quadrature voltage. The phase shift created by the reference pot is insignificant because of its relatively low impedance and internal construction. Figure 1 illustrates the circuit and Figure 2 its theory of operation.

The voltage ratio X is read directly from the dial of the reference pot, and the null voltage from the meter. An infinite resolution slide-wire type pot is desirable for the reference voltage divider. The phase shift is an angle whose tangent is equal to Mo/EX. For angles less than 6 deg, multiply the ratio Mo/EX by 57.3 deg to calculate a phase angle within the accuracy of the measurement technique. If a constant reference source is used, the dial of the voltmeter can be calibrated in phase shift directly.

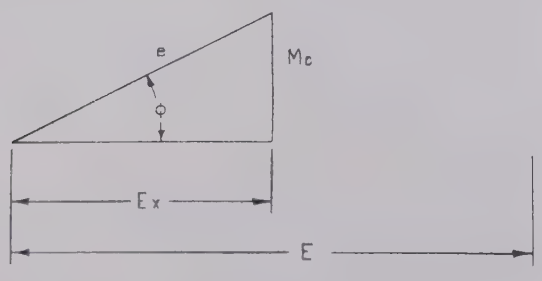


FIG. 2

It will be noted that as the phase angle becomes smaller, variations in EX produce an increasingly greater role in the variations of Mo. Hence, the accuracy of the technique for small angles is exceeded by its sensitivity. To achieve the indicated accuracy of 5 per cent, the reference pot should be accurate to ¼ per cent for angles less than 1 deg and the meter calibrated within 3 per cent.

For potentiometers, a small capacitor may be switched across the test component to determine the polarity (lead or lag) of the shift. The change in meter reading is then indicative of the polarity of the phase angle. For instance, if the shift is caused by capacitative reactance of the tested part, the condenser will augment them, increasing the negative phase shift and hence the null voltage. Similar techniques may be used for other components.

A plot of the phase shift of an unloaded ten-turn potentiometer can be easily calculated once its time con-

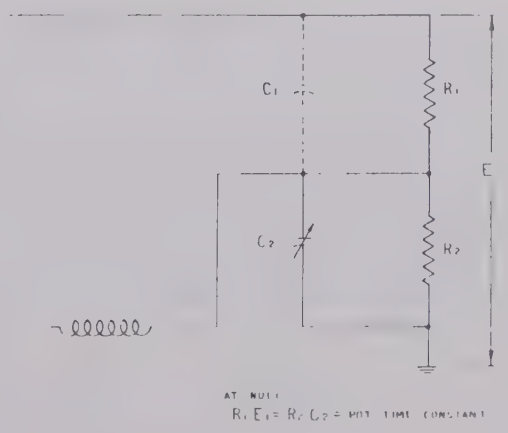


FIG 3

* *Trademark*

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stant is known. The time constant could be found by suitable calculation involving the phase shift measurements (obtainable by the balancing technique), but here is a direct way of finding it.

Figure 3 shows the setup R_1 is the entire ten-turn pot. R_1C_1 is the time constant produced by the distributed capacity of the pot. C_2 is a variable capacitor, and R_2 a small fixed resistor of approximately the same resistance as the pot. The phase shift through this resistor is too small to be significant. Only when the adjustable capacitor, C_2 is such that R_2C_2 equals R_1C_1 is the output voltage in phase with the input voltage. With the reference pot set near its halfway point, the in-phase component of the voltage will equal the voltage EX, but will be out of phase with EX depending on the time constant of R_1C_1.

This time constant can now be used in the following equation to find the quadrature voltage of any of the ten-turn pot's shaft settings.

$$Mo = EwRC\ (1-2S)\ (1-S)\ (S)$$

E = input voltage
w = radian frequency
R = potentiometer overall resistance
C = equivalent lumped capacity measured across end terminals
S = shaft position, in per cent of maximum rotation.

Similarly, one can calculate phase shift (in radians) by

$$\varnothing = wRC\ (1-2S)\ (1-S)$$

Since similar expressions can be derived for other pot types, one reading provides all the information needed to plot a pot's phase shift characteristics.

Rather than a slide-wire pot, an ideal standard voltage divider is a Gertsch Ratio Standard, Model RT-5. Resolution better than 0.0001 per cent is available together with a voltage ratio accurate to within 0.004 per cent. The advantage of this item is accurate output with very low internal impedance and extremely low phase shift.

The following additional information is supplied by the Engineering Department of Gertsch Products, Inc.

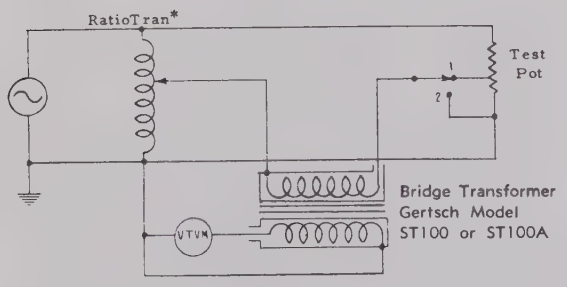


FIG. A

The circuit shown in Fig. A is a variation on the method described in the preceding article. Leads may be changed instead of using a switch.

In operation, the RatioTran* is adjusted to the best null with the switch in position 1. The RatioTran* then reads the inphase component of voltage ratio. The VTVM is read and the switch thrown to position 2. The RatioTran* is then adjusted to bring the VTVM back to the same reading. The RatioTran* then reads the quadrature component of the unknown ratio. This method has the advantage of eliminating errors from the null transformer voltage ratio. Also, the source voltage need not be accurately known.

A possible source of error when measuring phase angles by this method is the loading on the bridge caused by the null transformer and null detector. The method depends on measuring the remaining voltage at the best null. This voltage will be reduced because of current through the primary of the null transformer. Unless the impedance of the device under test is low compared to the impedance of the null transformer primary, the error will be serious. The circuit of Fig. B can be used to reduce this effect since a high impedance VTVM may be used directly as a null detector.

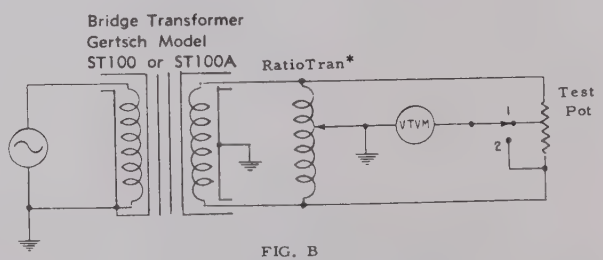


FIG. B

The bridge transformer may be omitted in this circuit if the source is capable of satisfactory operation as a floating source.

* *Trademark*

Engineering Bulletin Number 6

THE SHAFT DRIVEN RatioTran*

The Rotary RatioTran* is a precision shaft angle to AC voltage ratio transducer. It consists of a special tapped autotransformer, a split winding interpolating potentiometer, and printed circuit switches controlled by the potentiometer shaft. The whole assembly is encased in an anodized aluminum cylindrical housing with a servo type mounting and a precision ground ¼ inch shaft suitable for mounting in gear trains and servo systems. An internally mounted counter mechanism visible through a window gives the indication of the ratio of the instrument.

The Rotary RatioTran* has been designed in two models, a 1000 turn unit and a 100 turn unit. They feature characteristics which are most desirable for transducers. They have high input impedance, low output impedance, extremely good linearity and resolution (for example, linearity of .002% and resolution .0005%). The switching is so arranged that no transients occur. Components and materials of the best quality are used throughout to insure long and trouble-free life.

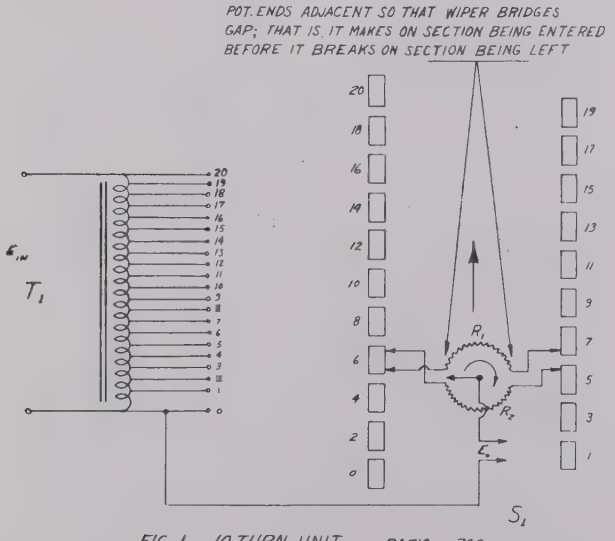
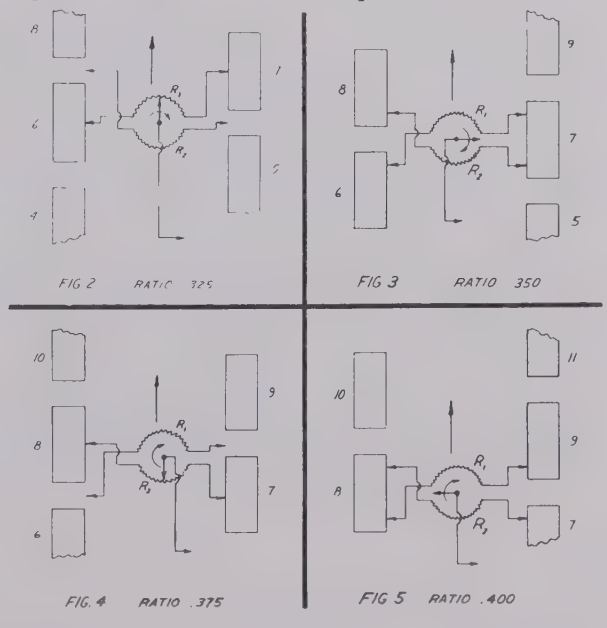

POT. ENDS ADJACENT SO THAT WIPER BRIDGES GAP; THAT IS, IT MAKES ON SECTION BEING ENTERED BEFORE IT BREAKS ON SECTION BEING LEFT
E_{in}
T_1
R_1
R_2
E_o
S_1

FIG. 1 10 TURN UNIT RATIO .300

Operation of the Rotary RatioTran* can be understood by referring to the illustrations. Fig. 1 shows how a ten turn unit would be constructed. T_1 is an autotransformer with twenty equal taps, including start and finish, brought out and labeled as shown. These taps are connected to the corresponding labeled fixed contacts on S_1. R_1 and R_2 are resistance windings on the special potentiometer. Each winding covers 180 degrees of the card. The ends of the windings are insulated so that the windings are electrically isolated from each other but are mechanically close enough so that the arrangement forms a continuous card covering the full 360 degrees. The wiper or arm is so constructed that it bridges the gap between the ends of the windings, that is, it makes contact on the winding being entered before breaking contact on the winding being left. The switch S_1 consists of the four moveable contacts shown which all move together and in synchronism with the potentiometer shaft such that for one revolution of the shaft clockwise the moveable contacts all advance the distance of one fixed contact. Figures 1, 2, 3, 4, and 5 show successive switch and potentiometer positions for one full revolution of the potentiometer. It will be noticed that the switching occurs always on the section of the potentiometer which is not being used. For example, Fig. 2 shows the situation for a ratio of .325, R_1 is being used to control the ratio, and R_2 is being switched. The converse is true in Fig. 4 for a ratio of .375. This process repeats itself over the whole range of ratio. Two taps are required for each rotation of the potentiometer.



* Trademark

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THE SHAFT DRIVEN RatioTran*

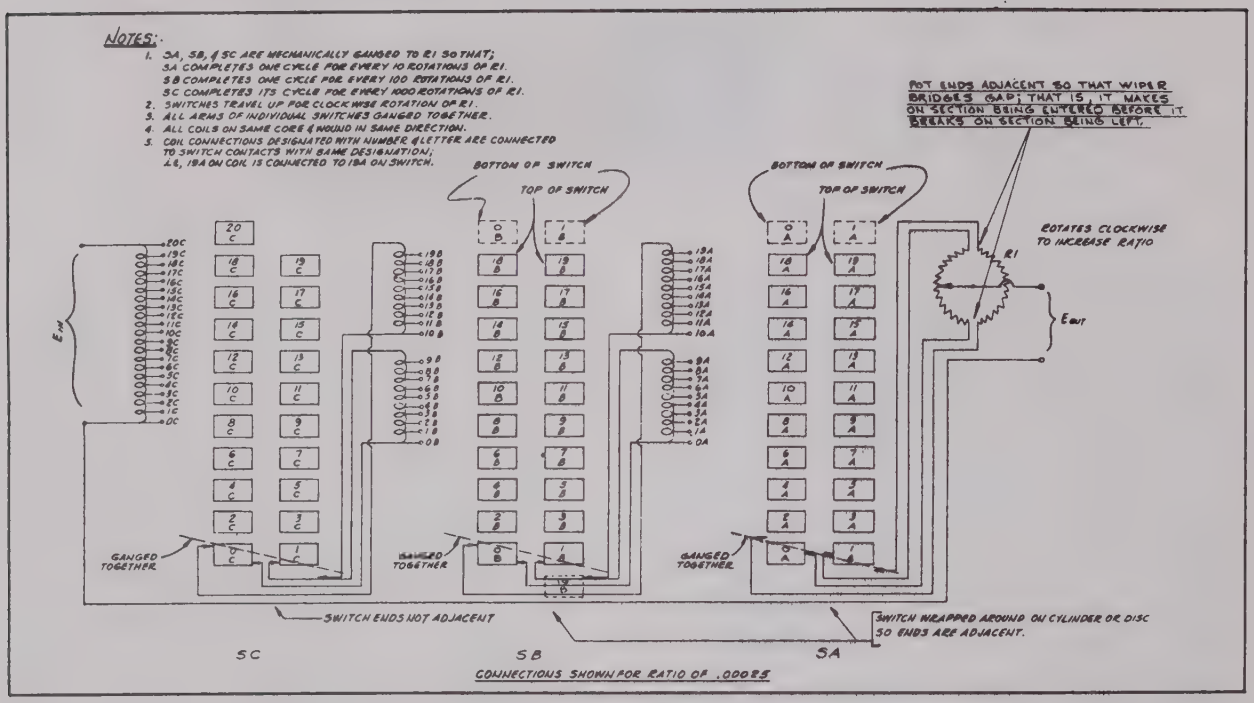

NOTES:
1. 5A, 5B, & 5C ARE MECHANICALLY GANGED TO R1 SO THAT;
5A COMPLETES ONE CYCLE FOR EVERY 10 ROTATIONS OF R1.
5B COMPLETES ONE CYCLE FOR EVERY 100 ROTATIONS OF R1.
5C COMPLETES ITS CYCLE FOR EVERY 1000 ROTATIONS OF R1.
2. SWITCHES TRAVEL UP FOR CLOCKWISE ROTATION OF R1.
3. ALL ARMS OF INDIVIDUAL SWITCHES GANGED TOGETHER.
4. ALL COILS ON SAME CORE & WOUND IN SAME DIRECTION.
5. COIL CONNECTIONS DESIGNATED WITH NUMBER & LETTER ARE CONNECTED TO SWITCH CONTACTS WITH SAME DESIGNATION; i.e., 19A ON COIL IS CONNECTED TO 19A ON SWITCH.
BOTTOM OF SWITCH
TOP OF SWITCH
ROTATES CLOCKWISE TO INCREASE RATIO
R1
Eout
Ein
GANGED TOGETHER
SWITCH ENDS NOT ADJACENT
SWITCH WRAPPED AROUND ON CYLINDER OR DISC SO ENDS ARE ADJACENT.
5C
5B
5A
CONNECTIONS SHOWN FOR RATIO OF .00025

FIG. 6

If the coil is broken down into groups of windings as shown in Fig. 6, the split groups of windings can be handled in the same manner as the potentiometer. The extension of this method to other number systems and other total potentiometer revolutions is obvious. The ability of this device to develop ratios slightly greater than one and slightly less than zero can be deduced from Fig. 6.

An interesting application of this device is the positioning of the carriage of a machine tool automatically from digital information with a simple control system. Fig. 7 shows a block diagram of a possible system. Using a lead screw having ten threads to the inch it would be possible to have a travel of ten inches with an absolute positioning accuracy of about one thousandth of an inch. If a 1000 turn Rotary RatioTran* and suitable gearing were used the ten inch travel could be extended. One requirement of the system is that a good lead screw is required since that part of the system is open loop.

Due to the fact that these devices have high input impedance and low output impedance, they can be cascaded directly to perform such functions as multiplying and squaring. These applications are useful in carrier type analogue computors.

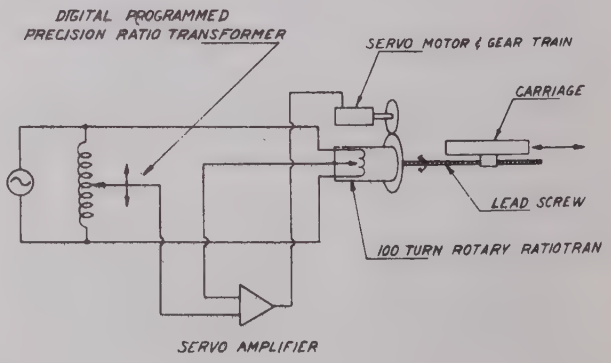


FIG. 7

* Trademark

Engineering Bulletin Number 7

USE OF A GERTSCH SHAFT DRIVEN RatioTran* FOR CALIBRATION OF PRECISION POTENTIOMETERS

GENERAL DESCRIPTION

The device to be described would be capable of automatically plotting a curve of the error of a precision potentiometer as a function of shaft rotation. Error would be plotted as a percentage of potentiometer rotation. Calibration to an accuracy of ±.01% terminal linearity should not be difficult.

DETAILED DESCRIPTION

A precision gear train is used to couple the shaft of the potentiometer under test to the shaft of the Rotary RatioTran*. Any error in this gear train will result in error in the overall system. A drive motor is used to slowly turn the mechanism throughout its range. Suitable limit switches must be provided to control this motor.

A bridge circuit is used to compare the output of the pot under test with the output of the Rotary RatioTran*. By means of a scaling transformer and a potentiometer linked to the Y axis, the recorder is made to plot error voltage as a percentage of input voltage. The voltage across the Y axis pot is derived from the same source as the voltage across the pot under test. By choosing the correct ratio in the scaling transformer, full scale pen deflection can be made to correspond to any desired percentage of potentiometer input voltage.

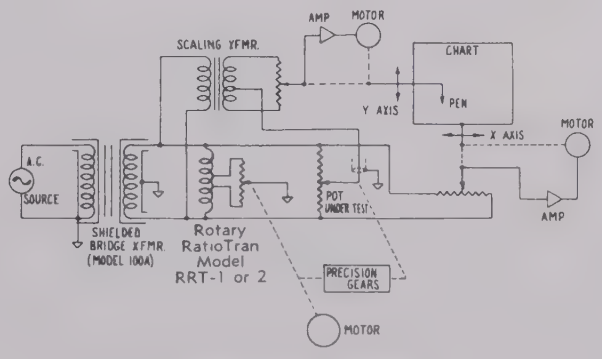
A second bridge circuit is formed by the Rotary RatioTran* and the X axis pot of the recorder. By this means the X axis position of the recorder is made to correspond to angular rotation of the Rotary RatioTran* and the pot under test. An alternate approach would be to use a single axis recorder and record error as a function of time with the pot driven at constant speed.

SOURCES OF ERROR

The ultimate limit of accuracy of this system is determined by the accuracy of the Gertsch Rotary RatioTran*. The units are available with a terminal linearity rating of .002% in a 1000 turn unit and .005% in a 100 turn unit.

Precision gear trains can be constructed to drive a potentiometer of 10 turns or more with gear train errors somewhat smaller than the Rotary RatioTran* error. Building a gear train to drive a single turn potentiometer with this accuracy would probably be difficult, and gear errors would probably predominate in this case. Backlash error can be eliminated by driving the mechanism in one direction only during tests.

Loading of the pot under test is another possible source of error. Since this is a bridge system, resistive loading can be almost eliminated by proper design of the bridge transformer and servo system. Since AC must be used on the pot under test, capacitive loading will also cause error. The bridge system connected to the pot under test can be shielded to reduce this error. The servo system should be made insensitive to quadrature voltage and a low frequency should be used. There will always be a certain amount of capacity in the pot itself which cannot be reduced by shielding. The effect of this capacity will increase with increasing pot resistance. For this reason, the system will be most accurate when measuring low resistance potentiometers.



POTENTIOMETER CALIBRATOR

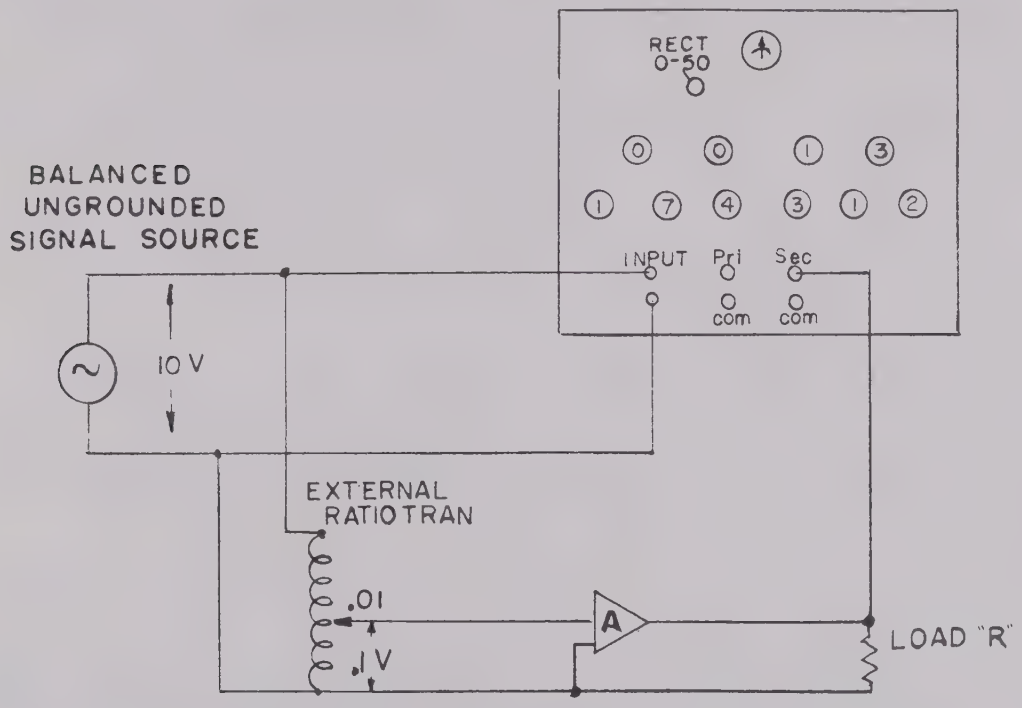
* *Trademark*

Gertsch

GERTSCH PRODUCTS, Inc.
3211 South La Cienega Boulevard, Los Angeles 16, California • UPton 0-2761 — VErmont 9-2201

SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NO

PRECISION AMPLIFIER GAIN AND PHASE MEASUREMENTS
(using RatioTrans or CRB Complex Ratio Bridges)



I. TEST EQUIPMENT REQUIRED

A. ONE (1) Gertsch Complex Ratio Bridge CRB-1B or CRB-2B.
B. ONE (1) RatioTran, Gertsch Model RT-5 or equivalent.
C. Signal Source.

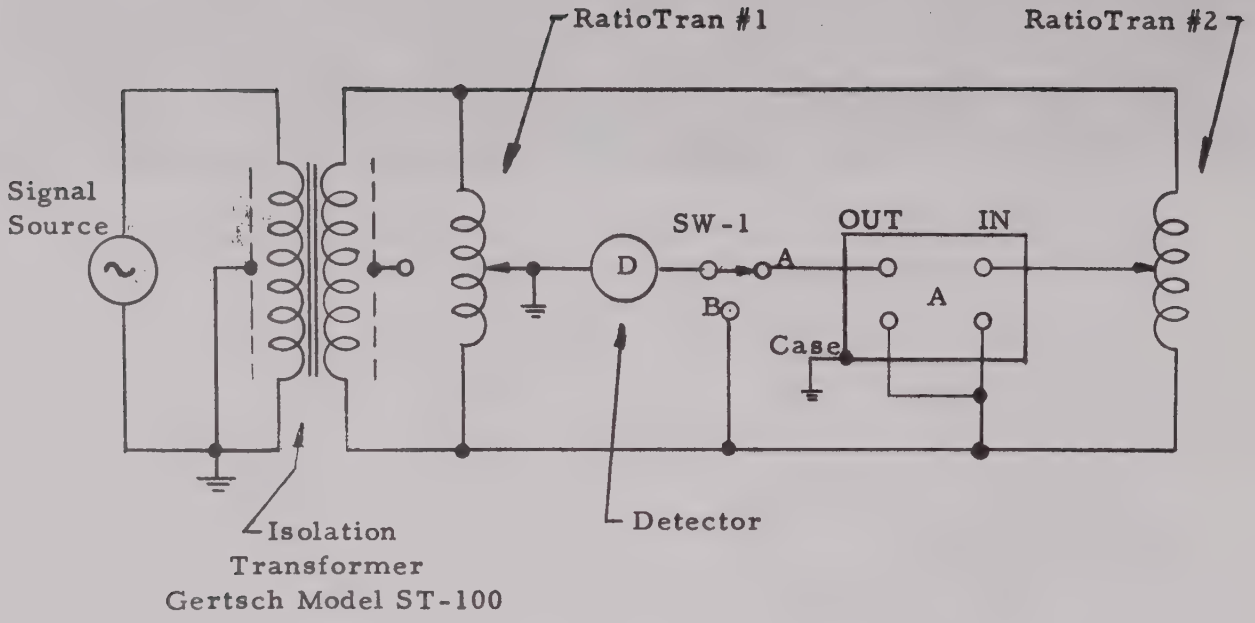
II. PROCEDURE

A. Connect test equipment and amplifier as shown.
B. Adjust CRB for proper in-phase and quadrature null.
C. At null, reading on CRB dials should be <u>divided</u> by ratio of external RT.

Example: External RT set to .01 ratio. At null, in-phase RT in CRB reads .174312. Amp. Gain = $\frac{.174312}{.01}$ = 17.4312

III. QUADRATURE

A. For quadrature, readings on <u>Rect.</u> position should be divided by the external RT ratio. <u>Tangent</u> and <u>Degree</u> positions read directly.



I. TEST EQUIPMENT REQUIRED

A. ONE (1) Isolation Transformer, Gertsch Model ST-100 or equivalent.
B. TWO (2) RatioTrans, Gertsch Model RT-5 or equivalent.
C. ONE (1) High Impedance Detector, VTVM or Scope.
D. Signal Source.

II. PROCEDURE

A. Connect the test equipment and amplifier as shown above. NOTE: If the amplifier ground and case are common, DO NOT connect to bridge ground. The bridge is grounded at one point only as shown.
B. Adjust RatioTran #2 for the proper amplifier input level.
C. Adjust RatioTran #1 for minimum output on detector.
D. Voltage gain of amplifier is ratio of RatioTran readings.

III. PHASE SHIFT MEASUREMENT

A. To measure phase shift, the output level on the detector is noted (the voltmeter reading if a VTVM is used, or the pattern height if a scope is used).
B. Switch SW-1 is moved to a position B and RatioTran #1 adjusted for same detector level as noted in III-A above.
C. The quadrature component of the amplifier output is now indicated on RatioTran #1. The amplifier phase shift is derived from the relationship:

$$\text{Tan } \Theta = \frac{\text{RatioTran \#1 (III-C)}}{\text{RatioTran \#1 (II-C)}}$$

where Θ = phase angle

MEASURING TRANSFORMATION RATIO AND PHASE SHIFT, PLUS FUNDAMENTAL AND TOTAL NULL

GENERAL

Since conventional synchros and resolvers are, basically, variable coupling transformers, it follows that they will normally have a leading time phase shift (ϕ) from primary to secondary as well as a maximum transformation ratio (N) at maximum coupling. Furthermore, since they are not "ideal" variable coupling transformers, the output voltage will never be zero and can, therefore, only be minimized. The fundamental and total null voltages are measured at this minimum output voltage position.

The output voltages of a synchro (CX) at 30° (first position of maximum coupling from EZ) can be represented by the following vector diagram. The outputs of resolvers, and other types of synchros are quite similar.

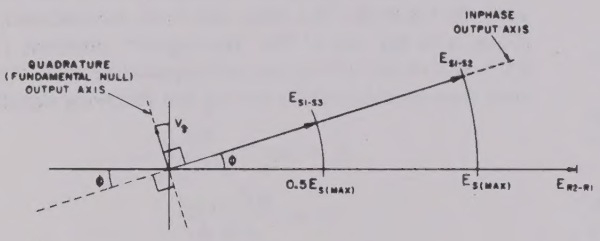


FIGURE 1. *Vector Diagram of CX Output Voltages at* $\Theta = 30°$.

DEFINITIONS

Transformation Ratio (N) is the ratio of the fundamental component of the no-load secondary voltage, at the first position of maximum coupling in the positive (CCW, as viewed from the shaft end) direction from electrical zero (EZ) to the fundamental voltage applied to the primary.

Typical values and tolerances: 0.1 to 2.3, $\pm$.1 to 4% (approximately 1.0 $\pm$.01 to .1% for some computational-type resolvers).

Phase Shift (ϕ) is the difference between the time phase of the fundamental component of the primary and secondary voltages, at the first position of maximum coupling in the positive direction from EZ.

Typical values and tolerances: 0° to + 20°, $\pm$0.5° to 4° (0° $\pm$1 to 4 minutes for some computational-type resolvers).

Fundamental Null is the fundamental component of the minimum output voltage. Fundamental null voltage is synonymous with quadrature voltage (V_Q), since the inphase output voltage at this point is zero. Referring to figure 1, note that V_Q could *not* be measured at the angle shown, because the inphase components are so much larger in amplitude.

Typical values: 15 to 90 MV

Total Null is the RMS value of the minimum output voltage, including harmonics.

Typical values: 20 to 120 MV

MEASUREMENT TECHNIQUES

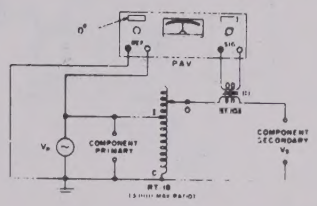


FIGURE 2. *N and* ϕ *Technique* # *1.*

PROCEDURE

(1) With PAV at 0°, adjust RT for an inphase null. RT ratio is termed "RT."

(2) Switch PAV to 90°, and record the secondary quadrature voltage (V_{SQ}).

(3) Solve the following equations:

$$\phi = \tan^{-1} \frac{V_{SQ}}{RT \cdot V_P} \qquad (1)$$

$$N = \frac{RT}{\cos \phi} \qquad (2)$$

Note, that a PDR cannot be used with this technique, unless ϕ is very small or constant. Also, note that RT > 1 if N cos ϕ > 1. If a large number of components of a particular type are to be tested, it may be worth while to make up nomographs relating V_{SQ}, RT, ϕ, and N.

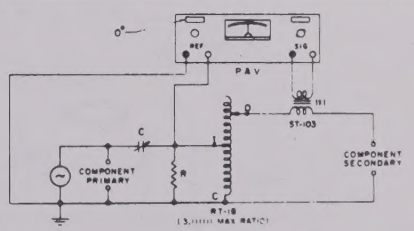


FIGURE 3. *N and* ϕ *Technique* # *2.*

PROCEDURE

(1) Adjust RT and C for an inphase and quadrature null with PAV at 0° and 90° respectively.

(2) Solve the following equations:

$$\phi = \tan^{-1} \frac{K}{C} \qquad (1)$$

$$N = RT \cos \phi \qquad (2)$$

where $K = \frac{1}{\omega R}$, and $R \ll Z_{in}$ of RT

Note, that a PDR cannot be used with this technique, unless ϕ is very small or constant. Also, note that RT>1 if N> cos ϕ. If a large number of components of a particular type are to be tested, it may be worth while to make up nomographs relating C, RT, ϕ, and N.

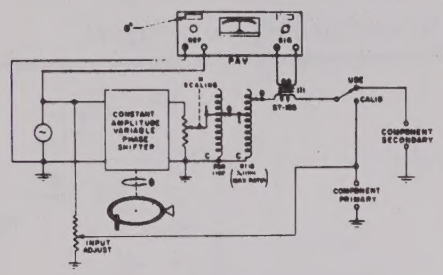


FIGURE 4. *N and ϕ Technique # 3.*

PROCEDURE

(1) Set PDR to 0%, and RT to 1.000. Put "Calib-Use" switch in the "Calib" position.

(2) Adjust "ϕ" dial, and "N Scaling" for an inphase and quadrature null on PAV. Set index on "ϕ" dial to 0°.

(3) Put "Calib-Use" switch in the "Use" position. Adjust "ϕ" dial and RT (or PDR if nominal N is specified) for an inphase and quadrature null on PAV.

(4) N and ϕ may now be read directly on RT (or PDR), and "ϕ" dial.

Note, the constant amplitude variable phase shifter may be of the synchro or resolver type, if care is taken.

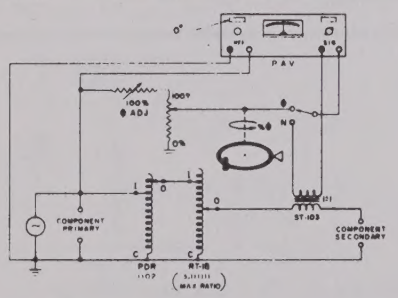


FIGURE 5. *N and ϕ Technique # 4.*

Note, this technique assumes that the secondary quadrature voltage (V_{SQ}) is directly proportional to ϕ, and is, therefore, only valid for small values of ϕ. The "100% ϕ adj" pot is used to set the 100% point on the "% ϕ" pot to correspond, in absolute amplitude, to $V_{SQ\,(max)}$. It is also assumed that cos ϕ = 1.000.

PROCEDURE

(1) Put "ϕ-N" switch in the N position.

(2) Adjust RT (or PDR if nominal N is specified) for an inphase null on the PAV. Switch the PAV to 90°, and note V_{SQ}.

(3) Switch the PAV back to 0°, and place the "ϕ-N" switch in the ϕ position.

(4) Adjust the "% ϕ" pot for a reading on the PAV equal to V_{SQ}.

(5) The RT (or PDR) and the "% ϕ" pot may now be read directly.

Note, if $V_{SQ\,(max)}$ is chosen to equal, say 1°, ϕ may be read directly in degrees from the "% ϕ" dial.

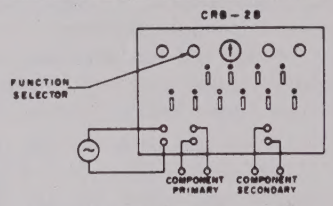


FIGURE 6. *N and ϕ Technique # 5.*

Basically, there are two techniques which may be used with the CRB-2B. The first, and most conventional, technique is to use one of the "rectangular" positions (5°, or 25°) and obtain an inphase and quadrature null. N and ϕ may then be obtained by solving the following equations:

$$\phi = \tan^{-1} \frac{RT_{quad}}{RT_{inphase}} \qquad (1)$$

$$N = \frac{RT_{inphase}}{\cos \phi} \qquad (2)$$

The second technique is to place the "Function" selector in one of the "angle" positions (1° or 10°), and obtain an inphase and quadrature null. ϕ can then be read *directly* from the quadrature RatioTran in terms of degrees. The maximum error in the 10° position is only .05°, and even less in the 1° position. N may be computed from (2) above.

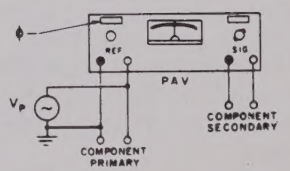


FIGURE 7. *N and ϕ Technique # 6.*

PROCEDURE

(1) Set PAV to 90°, and rotate reference phase shift dial for a quadrature null.

(2) Set PAV to 0° and read $V_{S(max)}$

(3) ϕ may then be read directly from the reference phase shift dial, and N may be obtained from the following equation:

$$N = \frac{V_{S(max)}}{V_P} \qquad (1)$$

Fundamental and Total Null Technique # 1. (See Fig. 7)

PROCEDURE

(1) Read Fund. Null (V_Q) in either the 90° or the Fund. position.

(2) Read Total Null in the Total position.